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Ministry of Water Resources

General Directorate for Water
Resources Management

Strategy for Water and Land Resources in Iraq

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Hydraulic and Water Quality Modelling

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This document is one of a series of technical reports published by the Ministry of Water Resources addressing issues relevant to strategic planning for the sustainable use of the water and land resources of Iraq.

The technical report presents hydraulic and water quality modelling which is intended to evaluate the likely effects in Iraq of possible changes in the stream flows arriving from upstream countries.

Report Issue and Revision Record

Rev	Date	Description
P1	August 2006	Preliminary when Phase 1 curtailed

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1 INTRODUCTION

1.1 Background

1.1.1   More than seventy percent of the water resources available to Iraq originate from outside its borders, and upstream utilization is progressing in the riparian countries, particularly in Turkey in the upper basin of the Tigris-Euphrates.

1.1.2   The SWLRI component for hydrologic analysis and water management system modelling of the Tigris and Euphrates basins in Iraq is tied to the reservoir simulation model development work conducted by the HEC in collaboration with Ministry of Water Resources (MoWR) staff. As part of the Iraq Marshland Restoration Program, a USAID-sponsored program from the Fall 2003 through Winter 2005, a Water Management System Model (WMSM) was established capturing the watershed characteristics and the functions of major water control and conveyance projects, including key points along the system for delivering water to the Marshes. Detailed operating criteria comprising reservoir rule curves, water supply objectives, and flood control targets were incorporated in the Tigris-Euphrates WMSM. Figure 1 illustrates part of the complex existing system for water control in Iraq as built into the WMSM.
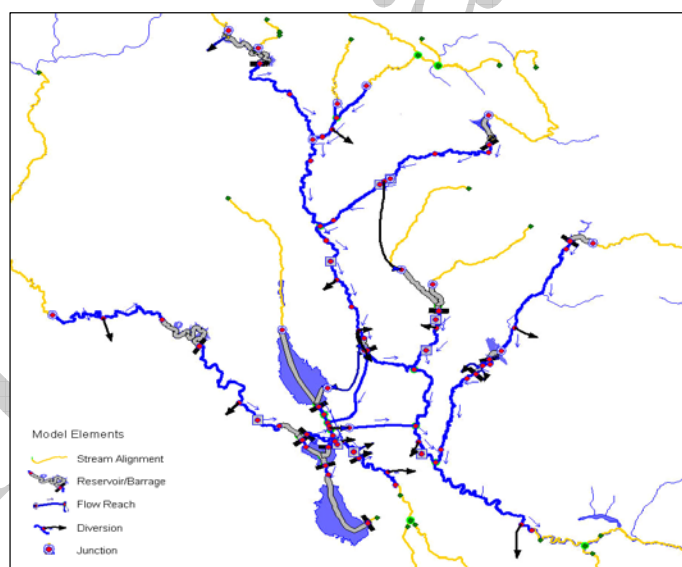
1.1.3   The model is intended to evaluate the likely effects in Iraq of possible changes in the streamflows arriving from upstream countries in the future.

1.1.4   Water quality is already a significant issue in the lower reaches of the rivers, and more so in the drains, and will become more serious when upstream countries use even more of the water in the two major rivers. Some potential interventions will need to be justified largely on their impact on water quality (e.g. flushing Lake Tharthar or damming the Greater Zab), and that may require quantification of the effects with a model. In order to provide a tool to model movement and changes in 'conservative' water quality parameters including salt, and the 'non-conservative' and mutually interacting ones such as oxygen content / BOD and the agricultural nutrients that come with irrigation return flows, a water quality extension to the WMSM was being

developed in collaboration with HEC. This extension would have enabled water quality simulations to be run as part of the WMSM. This model together with test models developed in another one-dimensional modelling package is described in more detail in the following sections.

1.2   The Modelling Approach

1.2.1   As part of the collaborative study with HEC, Mott MacDonald has developed water quality models for sample reaches of Tigris and Euphrates Rivers. The purpose of these models was to establish appropriate model coefficients to simulate the salinity level along the Tigris and Euphrates Rivers using the HEC-ResSim model.

1.2.2   The HEC-ResSim model has already been developed to simulate the flows along the Tigris and Euphrates Rivers systems. The flow routing procedure in this model is based on the 'Coefficient Method' as described in the HEC-5 software user's manual (HEC-5 was the precursor to the more recent ResSim modelling package). This method is based on simulating the downstream flow in a river reach by using predefined weighting factors for upstream inflows at various time lags. The weighting factors are defined to predict the discharges by conserving the mass within a river reach.

1.2.3   In order to obtain the salinity level at the downstream location of a river reach the same procedure of 'Coefficient Method' has been used. This procedure allows compatibility with the flow routing model and conserves the mass of both flows and salt in the river reaches and nodal locations.

1.2.4   HEC has already developed the scripts to simulate the salinity level for river reaches and the ResSim model can be used to study any water allocation and distribution scenarios. This is the subject of a separate report published by HEC. The weighting factors can be defined using the results from the hydraulic and salinity simulation models applied to sample reaches of Rivers Tigris and Euphrates.

1.2.5   During the study period Mott MacDonald has been continuously liaison with HEC to modelling strategies and to develop the salinity modules within HEC-ResSim. This involved arranging regular conference calls and visits by Mott MacDonald staff to the head office of HEC in California. This collaboration was important to ensure that the water quality modelling could be integrated with the water resource modelling in ResSim as efficiently as possible.

1.3   Capacity Building

1.3.1   In order to apply the HYDRO-1D model and to gain a good understanding of the modelling procedures Mott MacDonald have undertaken a training programme in their office in Cambridge, UK for the specialist staff from the

Ministry of Water Resources in Iraq. These trainees received a copy of the model and the model user manual at the conclusion of the training.

2   CONCEPTUAL MODEL FOR SALINITY

2.1   Conceptual Model for Nodes and Reaches

2.1.1   The methodology used to develop the HEC-ResSim model to simulate the water quality determinands are outlined in the diagrams and equations below. The model conserves the mass at nodes (river confluences, diversion points, etc) and along channel reaches. The particular case of reservoirs is considered in Section 2.2.

2.1.2   **Case 1 - Continuity Equation (Nodes)**
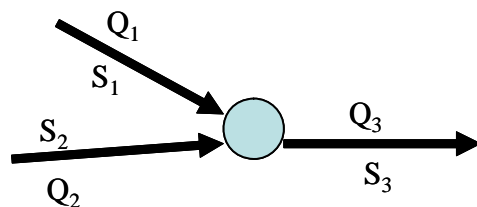
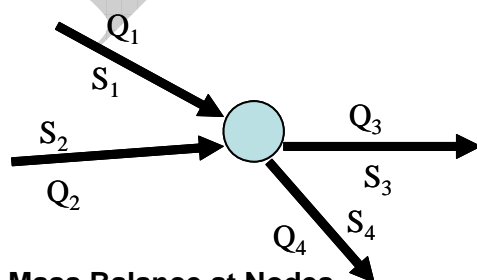**Mass Balance at Nodes**

$Q_3 = Q_1 + Q_2$

Salt Balance

$S_3 = (Q_1S_1 + Q_2S_2)/Q_3$

Where:

Q_1, Q_2	=	nodal inflows
S_1, S_2	=	salinity corresponding to inflows Q_1 and Q_2 respectively
Q_3	=	outflow
S_3	=	salinity of outflow Q_3

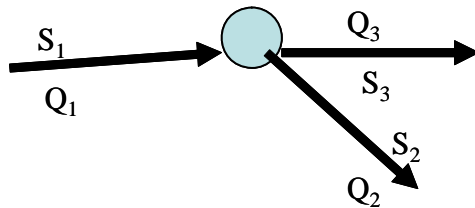2.1.3   **Case 2 - Continuity Equation (Nodes)**

Mass Balance at Nodes

$Q_3 + Q_4 = Q_1 + Q_2$

Salt Balance

$$S_3 = S_4 = (Q_1 S_1 + Q_2 S_2)/(Q_1 + Q_2)$$

2.1.4   Case 3 - Continuity Equation (Nodes)
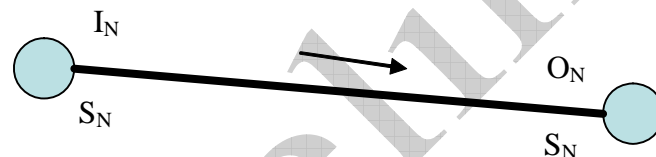

Mass Balance at Nodes

$$Q_3 + Q_2 = Q_1$$

Salt Balance

$$S_3 = S_2 = S_1$$

Continuity Equation along a Channel Reach

HEC-ResSim simulates the downstream flow in a channel reach based on a weighted combination of inflows from various time lags at the upstream end of a reach:

$$O_N = C_1 I_N + C_2 I_{N-1} + C_3 I_{N-2} + \ldots\ldots\ldots\ldots..$$

Where:

O_N	=	ordinate of outflow hydrograph at time n
I_N, I_{N-1}, etc.	=	ordinates of inflow hydrograph at times n, n-1, etc.
C_1, C_2, etc	=	routing coefficients, as coefficients of inflow

Salt Balance

$$S_{ON} = (C_1 I_N S_{IN} + C_2 I_{N-1} S_{IN-1} + C_3 I_{N-21} S_{IN-3} + \ldots\ldots)/O_N$$

Where:

S_{ON} =   salinity level at time N at the downstream end of a reach

S_{IN}, S_{IN-1}, etc   =   salinity level at time N, N-1 etc. at the upstream end of a reach

2.2   Reservoirs

2.2.1   HEC-ResSim simulates the outflows from a reservoir as a time series of discharges based on operating rules. The water balance equation is given by:

Rate of change of storage = Inflow – outflow – losses

2.2.2   Estimating the salinity of outflow from a reservoir is a complex procedure. Although the hydraulic and salinity model network has been developed for the Tharthar Reservoir and the model has been tested, the data available is too sparse to derive the model coefficients for this reservoir. Further monitoring of discharges entering the reservoir and releases from the reservoir with their salinity concentration is essential to maximise the benefit of the Tharthar Reservoir model. The data used for the test model and the possible modelling procedure for reservoir simulations are discussed further in Section 3.

2.3   Lag Coefficients for River Networks

2.3.1   The lag coefficients for the flow routing component and the solute transport process in a river system depend on several factors as summarised below.

- Selected duration of time step for the model runs;

- Distance between nodal points (sub-divided reach length of the river);

- Discharge and hydraulic parameters of the river system.

2.3.2   There is a distinct difference between the lag coefficients associated with flows and the transport of contaminants in a river system. The lag coefficients associated with flows are related to the celerity of the flood wave, whereas for the transport of contaminants they are related to the velocity of the fluid particles and the dispersion characteristics. If we simplify the dynamic equation to the diffusive wave the flow equation can be represented by:

$$\frac{\partial Q}{\partial t} + c \frac{\partial Q}{\partial x} - D \frac{\partial^2 Q}{\partial x^2} = 0$$

2.3.3   In the above equation c is the celerity of the flood wave which is higher than the velocity of flow. The above equation is valid for the transport of pollutant in a river system and in this case the celerity in the advection equation is replaced by average velocity of the fluid particle and the discharge is replaced by the concentration of contaminant. Salinity is a conservative parameter. For a non conservative determinant an additional term is

introduced in the above equation to incorporate the degradation rate of the contaminant. This means that the lag coefficients for non-conservative determinants will be different to those for conservative determinants.

3   MODELLING APPROACH FOR TEST REACHES FOR SALINITY ANALYSIS

3.1   Introduction

3.1.1   The sample hydraulic and salinity models have been developed using Mott MacDonald's in-house software HYDRO-1D for the following regions:

- Tigris River in the vicinity of Baghdad City;

- Tharthar Reservoir.

3.1.2   Of the above sample studies the former has been used to assess the weighting factors for channel reaches while the latter has been developed to estimate the weighting factors for reservoirs and lakes. The models have been tested using the existing data with estimated values. In order to achieve the maximum benefits of both models future monitoring of flows and salinity concentrations are very important.

3.1.3   The sample regions are shown in the following figures.

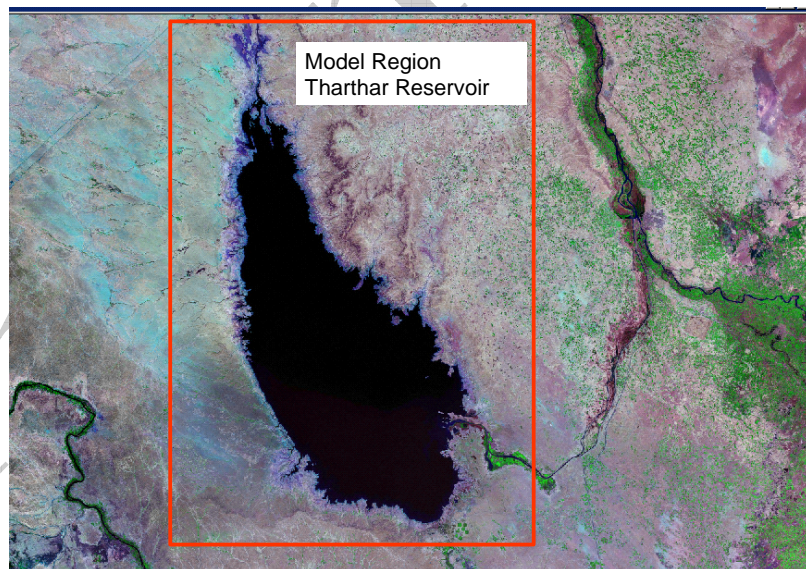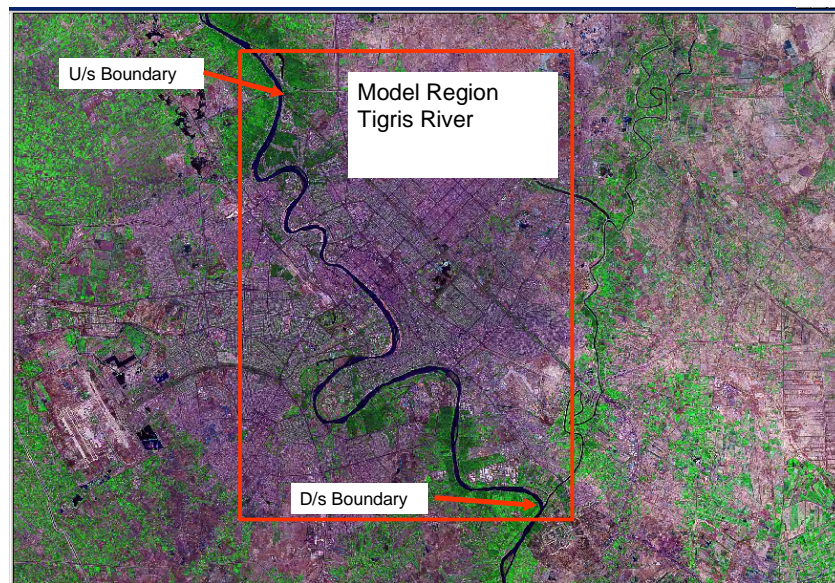**Figure 3.1: Model Region - Tharthar Reservoir**

Figure 3.2: Model Region – River Tigris

3.2 Data Available

Topographic Information

3.2.1 To build a one-dimensional hydraulic model of river reaches and lakes it is necessary to have cross section data or bathymetric survey data. At the start of development of the test bed models no cross section data was available so it was necessary to develop the required data from other sources of information.

Flow Data

3.2.2 Flow data sets have been prepared by HEC for inflows to the ResSim model and flows at intermediate points, such as the inflow to Tharthar reservoir from the Tigris, can be extracted after a model run.

Water Quality Data

3.2.3 Hand-written water quality record sheets were received for various gauging sites on the Tigris and the Euphrates. The periods of data covered in the records are shown in the following table. The timestep for the data collection varied between gauging stations and also through each record between monthly data and as frequent as daily data for some periods of record although there are extensive periods of missing data. The lengths of the data sets shown below are for the salinity or conductivity data records although further data series are present at most sites for other water quality parameters.

3.2.4   Perhaps most significantly, although most of the record sheets where referenced to particular gauging sites along the watercourses there is no indication of a location for each of the sites. A grid reference for each gauging station would be very useful for any future work. This would enable the precise location of the observed readings to be used including for example whether the…

Table 3.1: Availability of Water Quality Data Series for River Gauging Stations

River	Location	Period of Record
Tigris	Srai Baghdad	1971-2000
	Amara	1977-2002
	Baghdad	1979-1990
	Mosul	1971-2001
	Samarra Barrage	1974-2001
Shat al Arab	Al Qurna	1971-1990
Euphrates	Al Hindiah Dams	1971-1998
	Al Ramady Dams	1971-2001
	Al Samawah	1973-2002
	Di Qar	1978-2002

3.2.5   Twenty-three other record sheets were available but the gauging locations were not marked clearly on the sheets.

3.2.6   Monthly salinity observed data was used from the records for Baghdad for the test channel reach model. The model was run for 1990 using this available data.

3.3   Model Development for Tharthar Reservoir

3.3.1   Tharthar Reservoir was selected to assess the salinity distribution within for a test reservoir using the HYDRO-1D model. The Tharthar Reservoir is a key component of the water control infrastructure in Iraq and was originally designed to be a natural sink for flood waters from the Tigris. The reservoir is now connected by various drainage channels to both the Tigris and the Euphrates although increased salinity largely due to high evaporation rates is known to be a problem. Inflow from the catchments at the northern end of the reservoir is minimal in comparison to the Tigris drainage channels entering the reservoir at the southern end near the outlet works and the dam. Due to the layout of the inflow and outflow points there is only likely to be active exchange of water in the southern part of the lake. To fully model the system, a three-dimensional model of the reservoir could be developed although this would require detailed bathymetric, hydraulic and water quality survey data. However, in this case, given the approaches adopted for the modelling of the rest of the river network, a one-dimensional model is a valid approximation of the reservoir system.

3.3.2   The model allows for longitudinal variation of salinity level with area averaged salinity across any cross-section. The model covers a length of 60